

CONTAMINATION IN ORBIT OF GOES-8

Jack T. Sanders
Swales Aerospace

ABSTRACT

The GOES-8 satellite has lost some of its ability to dissipate heat over time. This is shown by the temperature increases over time of spacecraft and instrument components that are cooled with optical solar reflector (OSR) radiators. Contamination has a significant, well-documented effect on the solar absorptance (a_s) of OSRs. This document attempts to discern how much molecular contamination has collected on the Imager and Sounder radiant coolers by analyzing the increase in temperature of the vacuum cooler housing. In the first part, temperature change is transformed into solar absorptance units by a method devised by ITT. The second part transforms the solar absorptance gain into a molecular film thickness.

SYMBOLS

Values are given in both SI and U.S. Customary Units. The measurements and calculations were made in U.S. Customary Units.

a_s Solar Absorptance

da_s/dx Change in Solar Absorptance due to a change in thickness of contaminant

INTRODUCTION

GOES-8 thermal telemetry was used to evaluate the increase in temperature of the Imager and Sounder vacuum cooler housing, which is attached to the radiant cooler. Figure 1 shows the location of the radiant coolers on the spacecraft. The radiant cooler of each instrument faces towards the solar sail. Figure 2 shows a close-up view of the Imager instrument. The vacuum cooler housing temperature was compared to the instrument temperature by ITT to derive the change in a_s .¹ The radiant cooler is comprised of an OSR radiator and a vacuum-deposited aluminum (VDA) sunshield. The OSRs have an assumed beginning-of-life (BOL) a_s 0.080 and the VDA has a a_s of 0.10. The SCATHA experiment¹ shows that both materials have approximately the same change in a_s over time in the identical near-geosynchronous environment. The change in temperature is also related to the thermal emittance of both materials. The BOL thermal emittance of the OSR is 0.80 and that of the VDA is 0.02. Changes in emittance have

¹ R. Annable, GOES Radiant Cooler: OSR Solar Absorptivity Degradation Versus Time On Orbit, memo dated Sept 5, 2000.

been shownⁱⁱ to be very low, even for a high-absorption film like silicon oxide. This film was chosen as an upper bound on the change in emittance effect. The thermal emittance in reference 3 increases by 0.020 for a contaminant thickness of around 1000 Angstroms. The thermal emittance of the radiant cooler is the average of the VDA sunshield and the OSR radiator. This is dominated by the very high thermal emittance of OSRs (0.80); the effect of a contaminant is negligible. It is believed, therefore, that the change in temperature is dominated by the change in a_s with little effect from the change in thermal emittance.

It is estimated that approximately 240 Angstroms of molecular contamination has collected on the GOES-8 Imager and Sounder radiant coolers over 7.5 years. It can be reasonably assumed that the same mass flux falls on any optical port on the spacecraft. By extrapolating to ten years and accounting for a difference in mass of various standard spacecraft busses that could be used for future missions, it can be inferred that up to 600 Angstroms would deposit on similar surfaces during 10 years in orbit with a 2200-kilogram satellite (dry mass). This assumes that there is not a solar array or other spacecraft appendage in the field of view of the instrument radiant cooler, and no contribution from the instrument directly to itself.

RESULTS

Figure 3 shows the a_s calculated by ITT for the GOES-8 Imager and Sounder. An average effect is also included as a solid line. The least squares fit is also extrapolated beyond the 7.5 years of actual data to 10 years. It can be seen that the average change in a_s is 0.028 solar absorptance units over 10 years. It is also apparent that the solar absorptance is constantly increasing; it does not approach an asymptote. Another point is that the astromast and solar sail are in the field of view of the radiator. It is possible that the radiant cooler is contaminated by at least the astromast; the solar sail is probably too far away to have a measurable effect. Still, this provides a conservative evaluation of electrostatic re-attraction of contaminants to the satellite.

The next step is to transform the a_s values to molecular contaminant thickness. There have been several attempts to correlate a_s to thickness in ground testing and in orbit. A spacecraft was flown in the early 1990s by the Air Force to evaluate the contamination effect on optical solar reflectors.ⁱⁱⁱ Five OSR calorimeters and four TQCMs were used to evaluate the change in solar absorptance for a given contaminant thickness. The author reports measured values of 0.0086 to 0.014 solar absorptance units per $\mu\text{g}/\text{cm}^2$ (~100 Angstroms). These data are in agreement with the industry standard value of 0.01 solar absorptance units per $\mu\text{g}/\text{cm}^2$.

Another flight program^{iv} used contaminated and clean OSR calorimeters to evaluate the effect of energetic radiation on OSR performance. Fused silica OSRs were coated with 300 Angstroms and 600 Angstroms of poly-dimethylphenyl silicone (PDPS); a clean OSR was flown as well. All samples showed an increase in a_s during the 933 days of the test. It is assumed that the initially clean sample's 0.017 change in a_s is due to ESR, not radiation-induced changes in the fused silica. This indicates that there is

approximately 50 angstroms of molecular film on the clean sample. There are also 350 and 650 Angstroms on the two pre-contaminated samples. This translates to a a_s rate change of 0.02 per 100 angstroms of contaminant. PDPS is a moderately absorbing material and probably photopolymerizes at a moderate rate. However, a da_s/dx of 0.01 is chosen to make a conservative estimate of contaminant accretion. Also, Hall's experiment did not pre-contaminate any calorimeter; only electrostatic re-attraction of the satellite's mass flux resulted in contaminant collection.

Flight data shown in Figure 1 for GOES-8 indicates that after 7.5 years there has been a change in a_s of 0.024. This can be transformed to a contaminant thickness as described above of 240 Angstroms. Over 10 years, GOES-8 would likely accumulate 280 Angstroms of molecular film. Larger satellites would generate more mass flux^v and therefore more electrostatic return. If it is assumed that the larger spacecraft will have approximately the same relative mass of polymeric materials, then the rate of mass accumulation will be directly proportional to the dry spacecraft mass (no propellant). GOES-8 had a dry mass just under 1000 kilograms. Newer communications spacecraft that could accommodate future GOES missions have a dry mass of up to 2200 kilograms. If the ESR were assumed to vary as the ratio of the dry mass of a satellite to GOES-8's dry mass, then the molecular film on spacecraft surfaces would be about 600 Angstroms after 10 years on the largest spacecraft.

CONCLUSIONS

Optical solar reflectors and any other optical surfaces on a spacecraft in geosynchronous orbit will undergo degradation over time. The accumulation of contaminants can be measured by evaluating the change in solar absorptance of a contamination-sensitive surface. In this case, the OSRs on the GOES-8 Imager and Sounder radiant coolers were used to determine the amount of electrostatically re-attracted molecular contaminants which were primarily generated by the spacecraft, not the instruments themselves. Using a transformation of 0.01 solar absorptance units per 100 angstroms of contaminant film, the total accretion at the end of 7.5 years is 240 Angstroms for GOES-8. As the spacecraft grows in mass, more outgassed materials are created and more electrostatically re-attracted contaminants result. A 2200 kg (dry mass) satellite would provide about 600 Angstroms of ESR on spacecraft surfaces or instrument apertures.

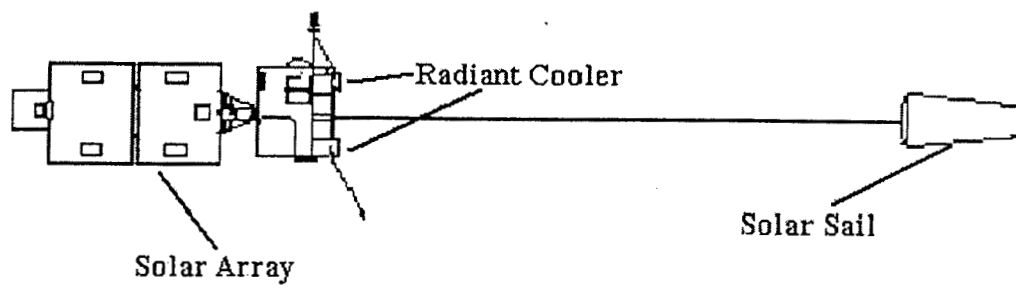


Figure 1: GOES-8 Spacecraft Configuration In Orbit

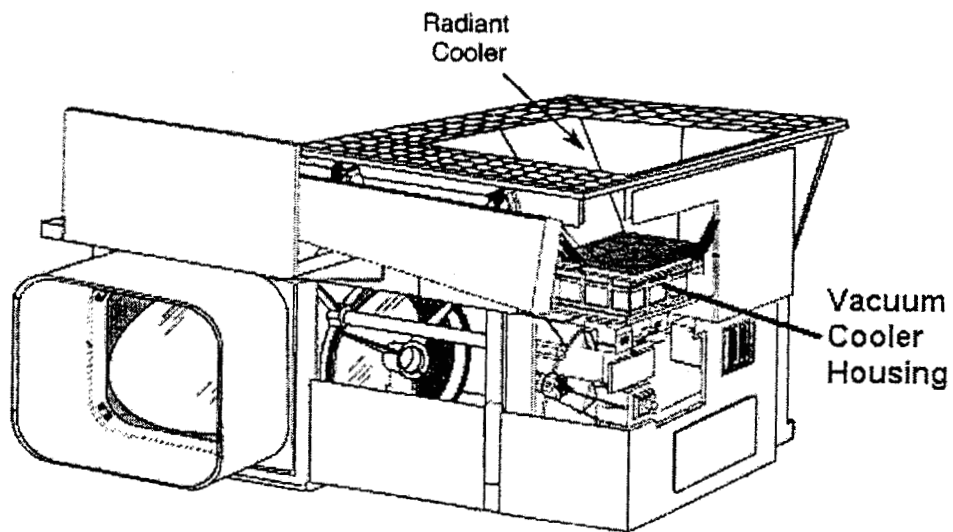


Figure 2: Imager Instrument

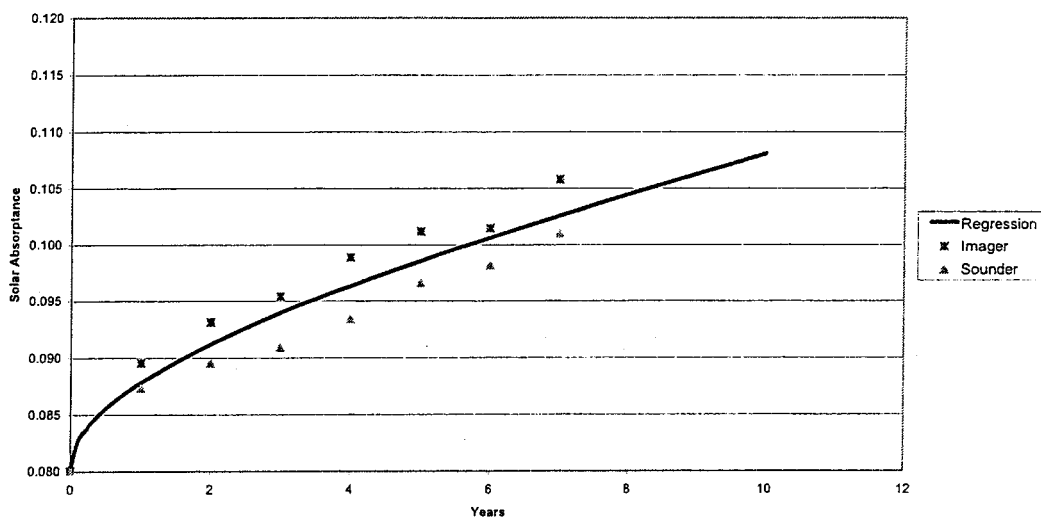


Figure 3: GOES-8 Change in Solar Absorptance

ⁱ D. F. Hall and A. F. Fote, *Thermal Control Coatings Performance at Near Geosynchronous Orbit*, Journal of Thermophysics and Heat Transfer, Vol. 6 No.4, Oct. – Dec. 1992

ⁱⁱ A.P. Bradford, G. Hass, J. B. Heaney, and J. J. Triolo, *Solar Absorptivity and Thermal Emissivity of Aluminum Coated with Silicon Oxide Films Prepared by Evaporation of Silicon Monoxide*, Applied Optics, Vol. 9, Feb. 1970.

ⁱⁱⁱ Hall, David F., *Flight measurement of contamination effects on fused silica mirrors*, SPIE Vol. 2864 (1996)

^{iv} Mossman, D. L., Bostic, H. D., and Carlos, J. R.; *Contamination induced degradation of optical solar reflectors in geosynchronous orbit*, SPIE Vol. 777 (1987)

^v Tribble, Alan C., and Haffner, James W., *Estimates of Photochemically Deposited contamination on the GPS Satellites*, J. Spacecraft, Vol. 28 NO. 2 (April, 1991), pg. 222-228